POLICY BRIEF
September 2020

Estimation of the Current Emission and Sequestration, As Well As Future Potential of Sequestration/Emission Reduction to Achieve Land Degradation Neutrality in India

teri
THE ENERGY AND RESOURCES INSTITUTE
Creating Innovative Solutions for a Sustainable Future

Authors

Dr Ajay Mathur, Director General, TERI

Dr J V Sharma, Director, Land Resources, TERI

Dr Reena Singh, Associate Director, Sustainable Agriculture, TERI

Dr Priyanka, Research Associate, Land Resources, TERI

Mr Siddharth Edake, Fellow & Area Convenor, Land Resources, TERI

Mr Yatish Lele, Associate Fellow, Land Resources, TERI

Dr Sangram Keshari Lenka, Associate Fellow, Nanobiotechnology Centre, TERI

Reviewer

Dr Sharad Singh Negi, Retd IFS, Vice Chairman, Migration Commission, Uttarakhand

Acknowledgements

We would like to acknowledge Childrens Investment Fund Foundation (CIFF) for funding this project.

Editorial and Design

Abhas Mukherjee, Sushmita Ghosh, and Sudeep Pawar

PUBLISHED BY

The Energy and Resources Institute (TERI)

FOR MORE INFORMATION

Land Resources Division, TERI, Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi 110 003, India |
Tel.: +91 11 2468 2100 or 2468 2111 | Fax: +91 11 2468 2144 or 2468 2145 Email: jv.sharma@teri.res.in | Web: www.teriin.org

TABLE OF CONTENTS

INTRODUCTION

Land is a fundamental resource for preserving forests and biodiversity, food production, facilitating the natural management of water systems, and acting as a carbon store. Appropriate land management can protect and maximize these services for society. Desertification, along with climate change and the loss of biodiversity were identified as the greatest challenges to sustainable development during the 1992 Rio Earth Summit. The United Nations Convention to Combat Desertification (UNCCD) is one of the three Rio Conventions which focuses upon Desertification, Land Degradation, and Drought (DLDD). Sustainable Development Goal (SDG) 15 also specifically focuses on combating desertification, land degradation, and restoring the degraded land. The UNCCD is an international agreement on good land stewardship. It helps people, communities, and countries to create wealth, grow economies, and secure enough food, water and energy, by ensuring land users have an enabling environment for sustainable land management. Through partnerships, the Convention's 197 Parties set up robust systems to manage drought promptly and effectively. Good land stewardship based on a sound policy and science helps integrate and accelerate the achievement of the SDGs, builds resilience to climate change, and prevents biodiversity loss (COP14, UNCCD). While India is a signatory to the UNCCD, the Ministry of Environment, Forest and Climate Change (MoEFCC) is the nodal ministry of Government of India that oversees implementation of the convention in the country. Stressing on the importance of the convention, the Prime Minister of India has called on the international community to set up a global water action agenda as the central theme to achieve land degradation neutrality. He announced that India will restore an additional 5 million hectare of degraded land by 2030, raising the total land to be restored in India to 26 million hectare (COP14 UNCCD). A flagship initiative has been taken under the UNCCD as part of India's commitment which includes restoration of land and sustainable land management to achieve land degradation neutrality by 2030. To date, 123 of the 170 countries affected by land degradation have committed to achieve land degradation neutrality. UNCCD (2017) defines Land Degradation Neutrality (LDN), as 'a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security, remain stable or increase within specified temporal and spatial scales and ecosystems'. This definition emphasizes the importance of ecosystem services, and the need to maintain or enhance the 'stock of natural capital associated with land resources and the ecosystem services that flow from them'.

India has also committed to meet its targets under the Nationally Determined Contributions (NDCs) made to the international community under the Paris Agreement (2015). According to the forestry target under NDC, India has committed to create additional carbon sink of 2.5 to 3.0 billion tonne of CO_2e through additional forest and tree cover by 2030. The commitment is backed with the fact that the emissions intensity of India's gross domestic product (GDP) has reduced by 21% over the period of 2005–2014. As per the Biennial Update Report-II of India, submitted to UNFCCC (2014), emissions from India stood at 2607.49 million tonne CO_2e in 2014. Out of the total emissions, the energy sector accounted for 73%, Industrial Processes and Product Use (IPPU) for 8%, agriculture for 16% and waste sector for 3% whereas the Land Use, Land-Use Change and Forestry sector accounted for about 12% of India's total emissions.

There have been several studies on the emissions of GHGs in India, and some of them deal with sectoral emissions in the country. Parikh and Gokarn (1993) is one of the earliest attempts at estimating emission levels in various sectors of the economy for 1983–84. Sharma, Bhattacharya and Garg (2006) analysed the total greenhouse gas (GHG) emissions from India for broad sectors such as energy, industrial processes, agriculture activities, land use, land-use change and forestry, and waste management practices for 1990, 1994, and 2000.

Five land-use sectors out of the total land-use land cover change in India have been identified for the study, viz., forestry (forests and tree cover), animal husbandry, wetlands, mining, and agriculture. There are other categories of land use such as habitation, infrastructure which are covered under other sectors, such as energy, transport, waste, and so on. These sectors have not been considered in the study to avoid double counting. Table 1 explains the area of different land-use sectors.

- Estimation of future potential of sequestration/(emission offset) to achieve land degradation neutrality.

Forests

Forest plays an essential role in maintaining earth's climate by stabilizing the concentration of GHGs from the atmosphere. Forests have an important role in mitigation and adaptation to climate change. Forests are considered as sink, reservoir, and source of carbon (IUCN 2016).

Table 1. Area of different land-use sectors

Land use Sectors	Area	Source
Forest and tree cover	80.72 Mha	ISFR (2019)
Agriculture	152.5 Mha	
Net sown area	140.13 Mha	Agricultural Statistics (2014–15)
Culturable wasteland	12.47 Mha	Agricultural Statistics (2014–15)
Animal husbandry	36.44 Mha	
Permanent pasture and other grazing land	10.26 Mha	Agricultural Statistics (2014–15)
Fallow lands	26.18 Mha	Agricultural Statistics (2014–15)
Wetlands	14.7 Mha	National Wetland Atlas (2011–12)
Mines	0.45 Mha	Mining Statistics (2014–15)
Other sectors		
Non-agricultural use	26.88 Mha	Agricultural Statistics (2014–15)
Barren and unculturable land	17 Mha	Agricultural Statistics (2014–15)
Total land	328.17 Mha	

The trees grown on farm land and outside notified forests have been considered under forestry sector.

This policy brief attempts to provide a more detailed perspective on CO_2 emission status of India using major land-use sectors for the year 2019–2020 based on the latest available secondary data. The major objectives of the study are as follows:

- Estimation of the emissions of the different land-use sectors in India
- The status of sequestration/emission offset of different land-use sectors in India, and

Direct and indirect benefits provided by forests in India are enormous. Forests provide direct benefits to the local communities in India in the form of fuelwood, fodder, timber, and non-timber forest produce (NTFPs) and are of significant religious and cultural significance to the other communities. Ecosystem services provided by forests is not limited to only carbon sequestration, as they help in disaster mitigation and control, conservation of soil and moisture, water retention and supply, and are reservoirs of terrestrial biodiversity (FSI 2011a; TERI 2013; Bahuguna and Bisht 2013).

As per the land-use classification scheme of the Government of India, forests are one of the land uses; the area under land-use class of forest comes under the provisions of Indian Forests Act, 1927 and referred to as Recorded Forest Area (RFA) (FRI 2013). As per ISFR 2019, the total forest cover of the country is 712,249 km^2 which is 21.67% of the geographical area of the country. The tree cover of the country is estimated as 95,027 km^2 which is 2.89% of the geographical area. The total growing stock of wood in the country is estimated to be 5915.76 million m^3 comprising 4273.47 million m^3 inside forest areas and 1642.29 million m^3 outside recorded forest areas. The average growing stock per hectare in forest has been estimated as 55.69 m^3. Total carbon stock in forest is estimated as 7124.6 million tonne.

Emissions

Forests have become a national resource of global concern. The global concern being about carbon sequestration and emissions of CO_2 by forests. As already mentioned above, forests are considered as source and sink of GHGs. India is committed to implementation of sustainable forest management. National Forest Policy, 1988 formulated four years before the Earth summit, embodies all elements of Sustainable Forest Management, and also has a strong policy, legal, and institutional framework for its implementation. A significant population of India is dependent on forest resources for fulfilling their needs. Fuelwood, fodder, and timber are three key direct services provided by forest to the community. Around 300 million people are deriving their full or partial livelihood from the forests unsustainably which is a major driver of forest degradation in the country as evident in the ISFR 2017. Annually, 85.29 million tonne of fuelwood are collected by the people living in the forest villages (ISFR 2019). Forest degradation directly impacts the emission and sequestration of GHGs. In India, there is a growing stock both within and outside forests. Trees outside forest (TOF) play a key role to meet the demand of fuelwood, timber, and other wood products for industries that are dependent on natural resources directly or indirectly. While calculating source and sink for the forestry sector, emissions and removals from both forests and TOF has been considered. The carbon present in timber is considered to be locked for 15–30 years and later gets converted to fuelwood as the end use. Therefore, three parameters, viz., fuelwood, paper and pulp, and forest fire have been considered for estimating annual emissions from the forestry sector, which are discussed in the ensuing sections.

Fuelwood

The major driver of forest degradation in India is unsustainable harvest of timber, fuelwood, fodder, and minor forest produce. In India, there is a growing stock both within and outside forests. Communities are largely dependent on fuelwood for their energy requirement. It is alarming to see that 216.42 million tonne of fuelwood is being used for energy requirement, out of which 58.75 million tonne comes from natural forests (FSI 2011). In 2019, 274.36 million tonne of fuelwood was to meet the energy requirement annually out of which 85.29 million tonne of fuelwood were collected from natural forests (ISFR 2019). The use of fuelwood in future will keep on increasing considering population growth, demand of rural energy, and energy requirement of brick kilns due to increased urbanization. The emissions from fuelwood have been calculated using fuelwood consumption data. The total CO_2 emissions from fuelwood consumption in 2020 has been estimated as 503.45 million tonne of CO_2e. Using the emission value of previous years, the values for 2030 and 2050 have been estimated. The emissions in 2030 will increase to 579.01 million tonne of CO_2e and to 620.46 million tonne of CO_2e in 2050, respectively. Figure 1 shows the CO_2 emissions from fuelwood consumption.

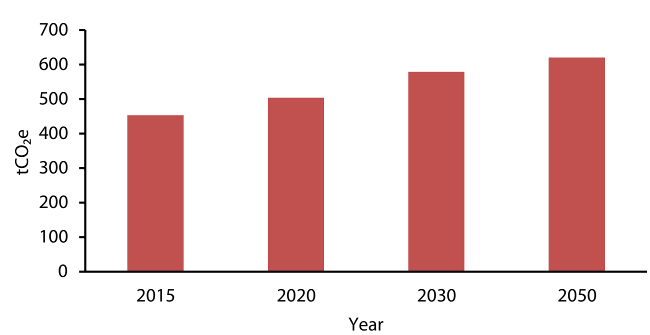


Figure 1 CO_2 emissions from fuelwood

Pulp and paper

Pulp and paper production is a highly energy intensive process and improvement of energy efficiency in this process is considered as promising measures for reducing industrial GHG emissions. The pulp and paper industry converts lignocellulose materials into pulp and paper products. The life cycle of forestry-pulp and paper industry products includes multiple process units such as forest tending, wood harvesting, preparation, pulping, papermaking, product distribution and use, with each value-added unit consuming a lot of heat and electricity. As the world's fourth-largest energy-consuming industry, the pulp and paper industry consumes large amount of energy, accounting for about 5% of the world's total industrial energy consumption, and its carbon emissions account for about 2% of the global industrial direct carbon emissions. The use of high-intensity energy and the burning and leakage of wood raw materials in the process of product conversion make the pulp and paper industry a highly polluting and high-emission industry.

According to a study conducted by TERI (2016), the annual biomass consumption, i.e. the amount of pulp extracted from forests to be used in paper and pulp industry was calculated to be 12.25 million tonne. Therefore, the CO_2 emissions from the paper and pulp industry was estimated as 22.47 million tonne of CO_2e. Based on this, we have projected the values for 2020, 2030, and 2050. The emissions have increased to 27.52 million tonne of CO_2e in 2020 and to 38.53 million tonne of CO_2e and 49.55 million tonne of CO_2e in 2030 and 2050, respectively. Figure 2 shows the CO_2 emissions in the paper and pulp industry.

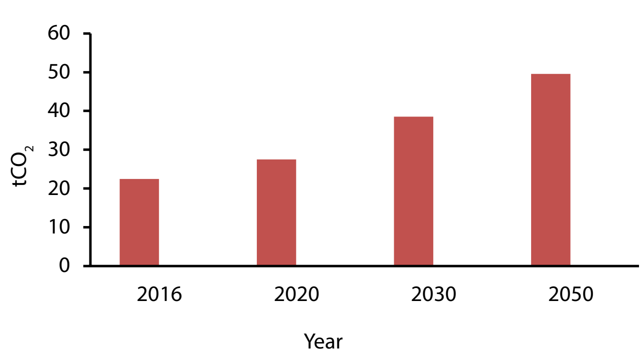


Figure 2 CO_2 emissions from paper and pulp

Forest fire

Forest fire is a well-recognized threat to biodiversity and a significant cause of ecological degradation. Forest fires are one of the major drivers of damage caused to forests in the country. Uncontrolled forest fires can lead to significant losses of forests and ecosystem services. Climate change influences forest fire frequency and intensity which results in forests becoming increasingly inflammable (Flannigan, Stocks, Turretsky, *et al*. 2008). The increasing duration of forest fire season, a number of large fires, and the frequency of severe fire years may be related to climate change (Venkataraman 2006). Forest fires in India are mostly anthropogenic; however, the intensity of fire depends on climate, fuel type, the wind, topography, and demography. The observations in the past 20 years show that the increasing intensity and spread of forest fires in Asia were largely related to the rise in temperature and decline in precipitation in combination with the changing inland use (Solomon 2007). There are shreds of evidence towards increased frequency of anthropogenic fires than in the past in Indian forests (Kodandapani 2013; Harikrishna and Reddy 2012). GHG emissions from forest fires strongly influence climate change (Venkataraman, Habib, Kadamba, *et al*. 2006). With respect to the area and amount of biomass burnt in India, the study by Srivastava and Garg (2013) reported that CO_2 emissions for different types of forest ranged from 74.95 Tg to 123.84 Tg over five time periods (2003, 2005, 2007, 2009, and 2010).

According to ISFR 2019, an analysis of fire-prone forest areas was carried out by FSI. Findings of the study indicate that nearly 4% of the country's forest cover is extremely prone to fire, whereas 6% of forest cover is found to be very highly fire prone. More than 36% of the country's forest cover has been estimated prone to frequent forest fires. Also an analysis has been done by overlaying the forest cover layer over the grids categorized into different fire-prone classes to assess the extent of forest cover under different intensities of fire proneness. A total forest cover of 658,118 km has been identified. Table 2 shows the area of forest cover in different fire-prone classes.

Table 2 Area of forest cover in different fire-prone classes

S No.	Category	Area (in km²)
1	Extremely fire prone	22,622
2	Very highly fire prone	42,495
3	Highly fire prone	75,952
4	Moderately fire prone	96,422
5	Less fire prone	420,627
6	Total area	658,118

The estimates of CO_2 emissions from previous studies vary significantly due to the use of very coarse resolution satellite data. Venkataraman, Habib, Kadamba, *et al.* (2006) have estimated an average of 10,101 km^2 of burnt area annually in India based on MODIS 2001–2003 data and reported 49–100 CO_2Tg y^{-1} from forest fires. Badarinath and Prasad (2011) reported about 6.34 CO_2Tg y^{-1} emissions with an average annual burnt area of about 2414 km^2 over 7 years in India. According to Saranya, Reddy, Rao, *et al.* (2016), CO_2, CO, and CH_4 are the major emissions during forest fires with an annual average of 105 × 106 tonne, 6 × 106 tonne, and 3.25 × 105 tonne, respectively, and the mean annual rate of carbon emissions was observed to be 1.26 Tg CO_2y^{-1}.

As per the study conducted by TERI in 2016, the estimated biomass consumed in forest fire contributing to CO_2 emissions million tonne in 2016 was 4 million tonne. The biomass consumed in forest fire in 2020 is estimated to be 4.46 million tonne. Therefore, the estimated CO_2 emissions from forest fire in 2020 is 8.1841 million tonne of tCO_2e. The projected value till 2030 and 2050 has been presented in Figure 3.

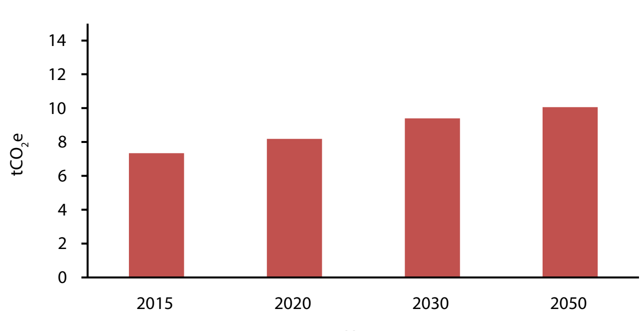


Figure 3 CO_2 emissions from forest fire

It was observed from the study that dense forests are contributing towards more emission release. As compared to open forests, dense forests lead to high biomass burning and consequently high carbon emissions. In this context, monitoring of fires is critical for long-term conservation management of dense forest, which is predominantly distributed throughout the reserve.

The total estimated CO_2 emissions from fuelwood, pulp and paper, and forest fire in 2020 is 539.14 million tonne of CO_2e. The CO_2 emissions will increase upto 626.91 million tonne of CO_2e and 680.11 million tonne of CO_2e in 2030 and 2050, respectively. Figure 4 shows the projections of CO_2 emissions till 2050.

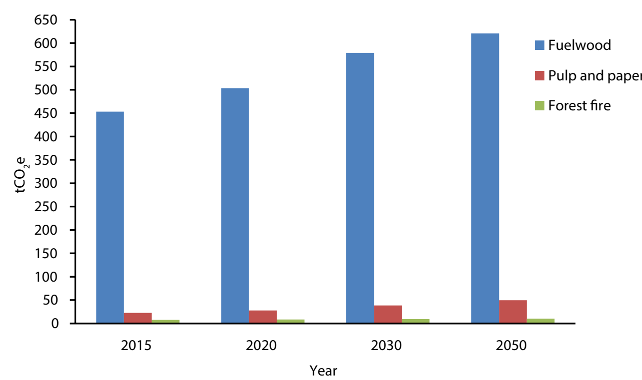


Figure 4 Projected CO_2 emissions from forestry sector

Sequestration

The gain and loss method is used for estimating the annual sequestration (ISFR 2019). The average annual productivity in forests and TOF is considered as 1.8 m^3 ha^{-1} y^{-1} and 10 m^3 ha^{-1} y^{-1} (ISFR 1987). The biomass expansion factor in India varies from 1–3.4. For dense forest, the value is taken as 3.4, for moderately dense forest it is taken as 2.5, and for open forests it is taken as 1.14 (Personal Comm. FSI).

Based on these values, carbon sequestration was estimated for forests and TOF. In the case of forests, the average annual productivity was multiplied with the total area and biomass expansion factor to calculate the value of carbon sequestered. In the case of TOF, the average annual productivity was multiplied with the total area to calculate the value of carbon sequestered.

Carbon sequestered from forests is estimated to be 631.54 million tonne of CO_2e, and carbon sequestered from TOF is estimated to be 293.84 million tonne of CO_2e. Therefore, the total carbon sequestered in 2020 is 925.38 million tonne of CO_2e.

Future potential to achieve land degradation neutrality

There are mainly three major strategies available to mitigate carbon emissions through forestry activities:

- Reducing carbon emissions that are caused from forest degradation.
- Increasing the forest and tree cover through reforestation and afforestation processes, and increasing the quality of existing forests at stand and landscape scale.
- Expanding the use of forest products sustainably.

India has committed to create an additional carbon sink of 2.5–3 billion tonne of CO_2e through additional forest and tree cover by 2030. It is suggested to take the baseline year for estimation of NDC targets as 2015 instead of 2005 as several technological and methodological advances have taken place over the years in mapping of forest cover in terms of better satellite data, higher scale maps, and improved mode of interpretation. In order to achieve the forestry NDC target, the level of emissions in the forestry sector needs to be reduced to a great extent. This can be done by promoting the use of LPG instead of fuelwood as the use of LPG has 90% emission efficiency in comparison to fuelwood.

As already mentioned above, 274.36 million tonne of fuelwood is being used to meet the energy requirement annually out of which 85.29 million tonne of fuelwood are collected from natural forests (ISFR 2019). The total CO_2 emissions can be reduced if fuelwood consumption is reduced and LPG is provided to all the households dependent on fuelwood for their energy requirements. According to a June 2017 study undertaken by the Centre for Science and Environment (CSE), through approximately 5 crore connections across several states, several of which are forest-rich, the 2016 Ujjwala scheme has reached a large underserved population, but the refilling of cylinders by the households still remains a challenge. While official figures state that 80% of Pradhan Mantri Ujjwala Yojana (PMUY) beneficiaries opt for at least one refill, field-based media reports suggest that number of refills is far from sufficient to meet the cooking needs of the households. According to a June 2017 study undertaken by CSE in Uttar Pradesh, many of the families have not opted for LPG connection despite being eligible, since refilling was not affordable. The effectiveness of the Scheme is dependent on whether people refill their cylinders or revert to previous fuels, including fuelwood wood chips. Considering the fact that efficiency of LPG cylinders is 90% and one household comprising 4–5 family members can use 1 LPG cylinder for 3 months, the total emission of 453.10 million tonne of CO_2e can be reduced in 2020 if the provision of LPG cylinders is made available for every household.

The pulp and paper industry has a heavy impact on GHG emissions, due to high energy requirements of its production process. Climate mitigation actions designed for Reducing Emissions from Deforestation and Degradation (REDD+) should not provide incentives to clear or convert natural forests and drain peatlands to develop pulpwood plantations. Pulp and paper companies should not be eligible for REDD project funding as long as they continue to source fibre for their mills from such activities. The mitigation strategies in order to control emissions from paper and pulp industry are as follows:

- Improving the energy efficiency of the process
- The use of cleaner fuels and the reuse of biomass generated by the process
- The use of cogeneration to cover the electricity and heat needs.

Animal Husbandry

Major source of GHG emissions from the animal husbandry sector are CO_2, CH_4, N_2O, fluorinated gases, and some other gases, which account for 18% of GHG emissions of India (FAO 2006). Livestock production results in methane (CH_4) emissions from enteric fermentation and CH_4 and nitrous oxide (N_2O) emissions from livestock manure management systems. CO_2 emissions from livestock cannot be estimated because the annual net CO_2 emissions are assumed to be zero. In the process of enteric fermentation as well as manure management, the CH_4 emission has showed an increasing trend for India (Figures 5 and 6).

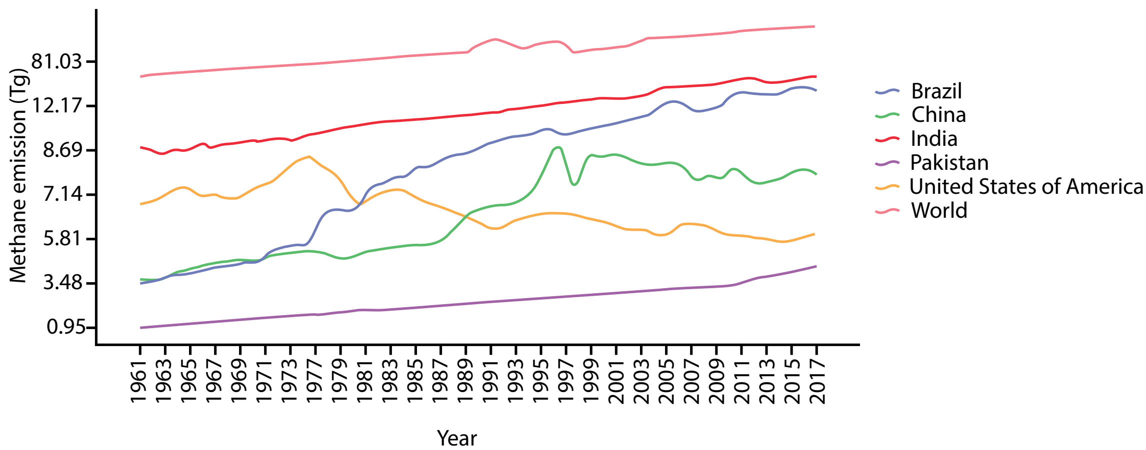


Figure 5 The periodic trend of livestock CH_4 emissions from 1961 to 2017 for the top five emitters – enteric fermentation

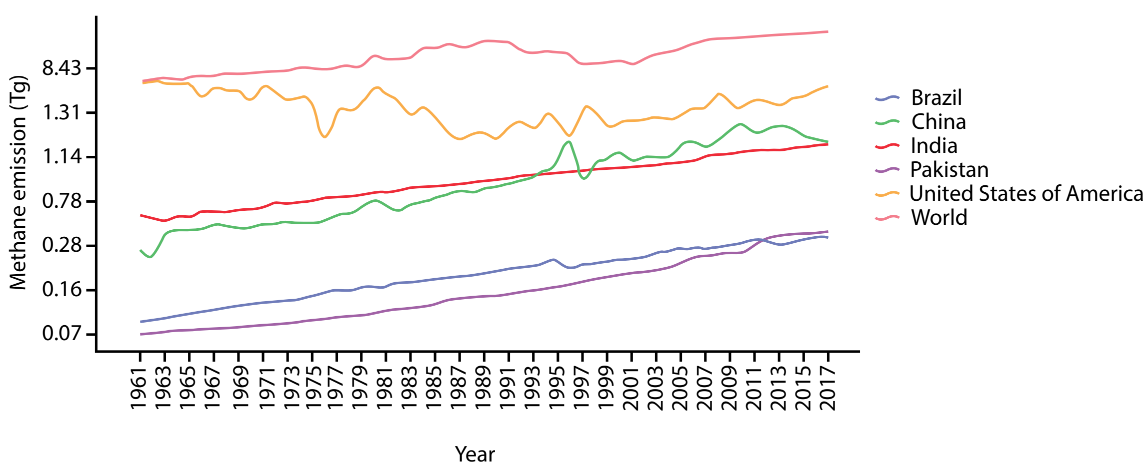


Figure 6 The periodic trend of livestock CH_4 emissions from 1961 to 2017 for the top five emitters – manure management

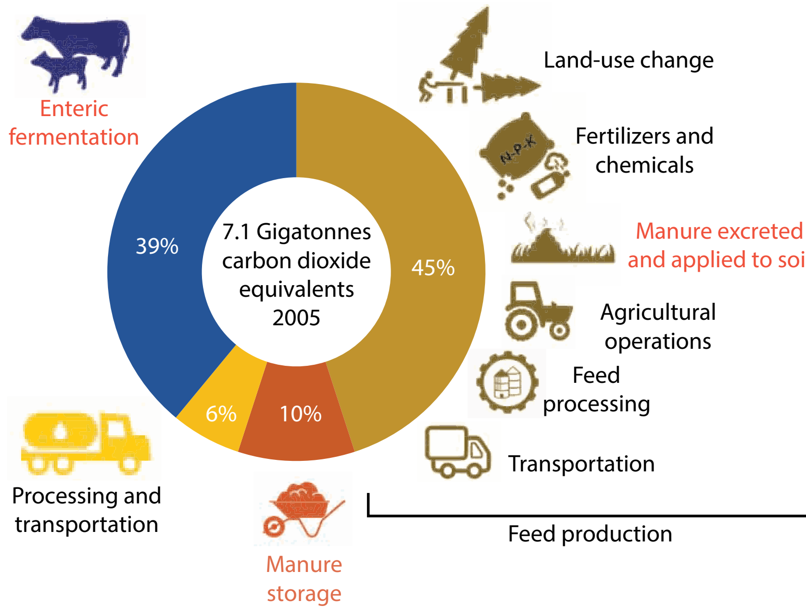


Figure 7 Livestock emissions by source

Source Adapted from FAO (2013)

Note Direct livestock emissions are shown in red

Emissions

All India population figures of different livestock categories for 2003 and 2007 (MoA 2007) were used as the basic activity data. The livestock considered in this estimation include cow, buffalo, sheep, goat, horses and ponies, donkey, camel, and pig. For future projection of livestock populations under different categories, data from 1950 to 2007 has been used. Age of cattle and their weight have been considered while estimating enteric fermentation. The cattle population has been divided into dairy and non-dairy categories, with sub-classification into indigenous and cross-bred types for different age groups (MoEF 2012).

Emission factors provided in India's Second National Communication for cows, buffaloes, and sheep have been applied. For the remaining livestock categories, default emission factors have been taken from the IPCC 1996 Revised Guidelines. Nitrous oxide emissions from manure management is due to conversion of manure nitrogen into nitrous oxide during storage. The emissions from manure management have already been included in the agricultural sector, therefore, we have not included it in animal husbandry. Figure 8 shows the emission level from different aspects in 2020. The total CO_2 emissions from the animal husbandry sectors is 248.58 million tonne of CO_2 equivalent (releasing 1 kg of CH_4 into the atmosphere is equivalent to releasing 25 kg of CO_2, releasing 1 kg of N_2O into the atmosphere is equivalent to releasing 298 kg of CO_2 – Source: Climate Change Connection report)

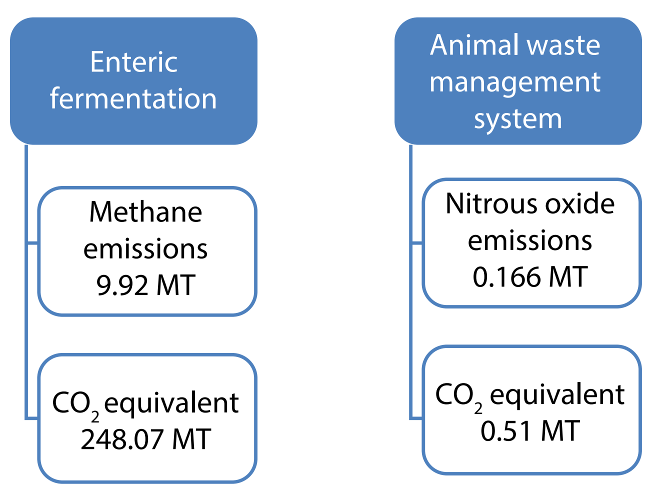


Figure 8 CO_2 emissions from enteric fermentation and animal waste management system

It was observed that the total CO_2 emissions from the animal husbandry sector would increase from 248.58 million tonne of CO_2e in 2020 to 254.53 and 266.60 million tonne of CO_2e in 2030 and 2050, respectively. Figure 9 shows the projections of CO_2 emissions from the animal husbandry sector.

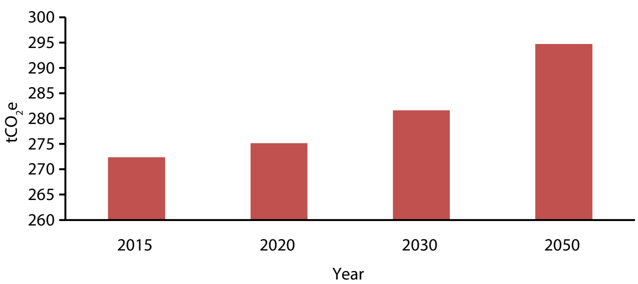


Figure 9 CO_2 emissions from animal husbandry sector

Future potential to achieve land degradation neutrality

Several methods have been proposed for mitigation of emissions of GHGs from livestock. Technologies that can reduce the amount of methane production in rumen of cattle or total release of methane into atmosphere are useful for efficient use of feed and making the environment more favourable. Mitigation of GHG emissions in the livestock sector can be achieved through various activities, including:

- Decreased emissions rate of only 10% will stabilize methane concentration in atmosphere at present level.
- Different animal feeding management, manure management (collection, storage, spreading), and management of feed crop production.
- Dietary manipulation, being one of the important strategies for CH_4 mitigation, is mostly possible on the condition that the livestock is reared in an intensive system.
- Aerobic composting of the manure can suppress CH_4 emissions.
- The use of composted manures in agricultural soils should be encouraged as it is a food source for the soil microbes. The interactions between manures and the microbes will increase the soil organic matter content making the soil more fertile and more sustainable for crop production.

Animal husbandry sector is an important contributor to the phenomenon of climate change as well as is sensitive to the phenomenon itself. Such approach needs to be devised which not only leads to curbing of the production of the GHGs but also, at the same time, keeps in mind the optimum production levels from the livestock sector. An approach has to be devised which focuses both on mitigation, to reduce the level of emission of gases contributing to global warming, and on adaptation, to support local communities in dealing with the impacts. Further, we need to understand the global trends in GHG emissions to understand the role of animal sector in particular.

Mining

The mining sector is one of the key sectors contributing towards the economy of the country. In 2014–15, the mining sector contributed almost 2.39% of India's GDP. Around 0.14% (459,200 hectare) of the total geographical area of the country (328 million hectare) is under mining (except fuel, atomic, and minor minerals) as on 2014.

Emissions

Mining activities are a major source of GHGs such as carbon dioxide and methane, which lead to pollution in India. India's direct CO_2 emissions in 2003–04 from all the sectors was 1128.4 MT, of which the share of mining and quarrying activities accounted for 0.07% (Parikh , Panda, Ganesh-Kumar, *et al*. 2009). In 2007, GHG emissions from the mining and quarrying sector accounted to 1,464,620 tonne of CO_2e.

The GHG emissions in mining sector occur in two scenarios: (i) Change in land use (forest to mines); (ii) Fugitive emissions during excavation of minerals.

i. Land-use change is a major threat to the forests of India resulting in emission of carbon. In India, there are 1604 cases in 25 states/UTs of diversion of forest land to mining purposes since 1980 to 2018. The total land diverted for mining under the Forest Conservation Act, 1980 accounts to 138,405.87 hectare (Lok Sabha, 2017 and 2018). To understand carbon emissions from land diverted from forests to mining, it is necessary to understand the total carbon stock of the forests diverted for mining from 1980–2018. The carbon stock of the forests was assessed based on the total land diverted and per hectare carbon stock in each pool of carbon. The total carbon stock was estimated to be 11,271,436.92 tonne based on the state-wise per hectare carbon stock in each pool as described by India's State Forest Report (2019). As the emissions from loss of forest cover are already considered in the forestry section, only the loss of carbon stock from soil was considered in this analysis to avoid double counting. The total carbon stock of SOC was estimated to be 6,576,895.05 tonne, which is 58.35% of the total carbon stock of all the pools. The carbon stock of SOC was converted to tonne of carbon equivalent using a conversion factor of 3.67. Hence, the emissions from diversion of forest land from mining are estimated to be 24,137,204.84 tCO_2e from 1980–2018.

ii. Coal mining is a major contributor to the build-up of GHGs in the atmosphere with release of significant CO_2, CH_4, and N_2O emissions from different mining activities as fugitive emissions (Pandey, Priyaranjan, Sahu, *et al*. 2018a). Emissions in coal mining occur during coal extraction, production, transportation, coal cleaning, land filling, use of electricity, and use of diesel for coal transportation. In this case, only the fugitive emissions occurring from coal excavation are considered to avoid double counting. Mohan, Dharmala, Anantha Kumar, *et al*. (2019) have documented the GHG emissions from the energy sector in India for a period of 10 years. As this study is focusing only on the fugitive emissions from coal mining, the fugitive emissions from coal post -mining were not considered. The study documented that the fugitive emissions from coal mining accounted to 24.82 million tCO_2e in 2015 as per the GWP-AR5 of IPCC. The study also documented a gradual rise in the fugitive emissions from 2005–15 in India. The highest emissions were recorded during 2009 with emissions of around 24,908,621 tCO_2e. Thus, on average, the fugitive emissions contributed to around 46% of the total emissions from fuel production sector and almost 2.2% of the emissions from all the sectors over 10 years.

Based on the trend of fugitive emissions over the years, the fugitive emissions for 2020 are estimated as 25,665,747.34 tCO_2e. In terms of the future scenario, the emissions by 2030 are expected to grow by 10% to 27,334,427.86 tCO_2e as compared to 2015. The emissions might increase up to **30,671,789 tCO_2e** by 2050.

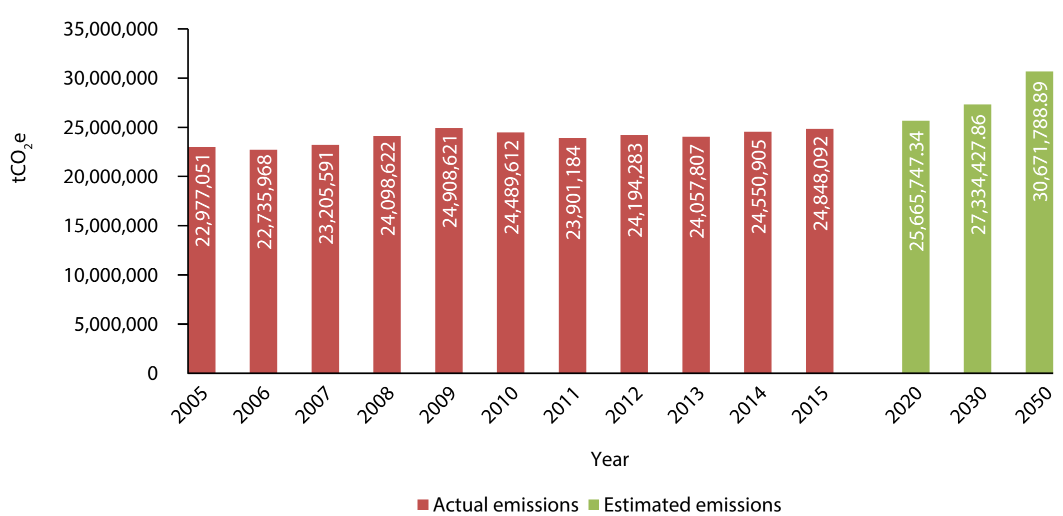


Figure 10 Total CO_2 emissions and estimated emissions till 2050 from wetlands

Sequestration

The sequestration potential of the rehabilitated/reclaimed mines has been less studied in India. Tripathi, Singh, and Hills (2016) studied a re-vegetated mine from Singrauli, India from 2 years to 19 years. The study resulted to the fact that the average calculated annual carbon budget was 8.40 T $ha^{-1}y^{-1}$. The above ground biomass increased 23 times and below ground biomass increased 26 times during the years of study. Das and Maiti (2016) estimated the carbon sequestered in a reclaimed coal mine dominated by plantation of *Albizia lebbeck, Dalbergia sissoo,* and *Bambusa arundinacea*. The total C stock in reclaimed site was calculated as 30.3 Mg C ha^{-1} (equivalent to 111 Mg CO_2 ha^{-1}).

A study by the Indian school of mines, Dhanbad on comparing three ecosystems such as forests, restored mine and unrestored mine found that the carbon sequestered by natural forest was highest (378.52 tCO_2 ha^{-1}) followed by eco-restored mines (116.54 tCO_2 ha^{-1}) and unreclaimed dump (47.63 tCO_2 ha^{-1}). The carbon sequestered by reclaimed mines is almost 2.5 times more than that of unreclaimed mines. The carbon dioxide sequestration potential of the reclaimed mine in Jharia, Dhanbad was found 133.3 t ha^{-1}, of which carbon density was highest in *Dalbergia sissoo* (Mukhopadhyay, Masto, and Ram 2016).

Future potential to achieve land degradation neutrality

The impact of deforestation in the case of land-use change should be mitigated with the use of reclamation, rehabilitation, and restoration technologies once mining in the particular area is completed. The most suitable way to sequester carbon is through afforestation techniques. Specific plant species should be identified based on the area and afforestation/reforestation activities should be undertaken at these areas.

Some of the mitigation strategies which could help reduce fugitive GHG emissions from coal mining are techniques such as flaring, methane purification, solvent adsorption, pressure swing adsorption, cryogenic separation, membrane separation, power generation using methane, production of methanol and carbon black, reactor technologies, concentrators, mine methane utilization in gas turbines, etc. (Pandey, Gautam, and Agarwal 2018b).

Wetlands

Wetlands cover about 5–8% of the earth's surface and contain 20–25% of global terrestrial carbon (350–535 Gtor billion tonne C) (Gorham 1995; Mitsch and Gosselink 2015). Being highly productive ecosystems, they sequester carbon and also store carbon-rich organic sediments. However, wetlands are not included in the official nine-category land-use classification followed in our country. This is despite their importance as land use providing numerous ecosystem services such as groundwater recharge, fisheries, and biodiversity.

In India, wetlands are broadly categorized into inland wetlands and coastal wetlands (both natural and human-made).

Based on the net balance of the three inter-related processes of the carbon cycle within the wetland ecosystems, i.e. carbon fixation, respiration and emission, wetlands can either act as source or sink of GHGs (Shaher, Chanda, Hazra, *et al*. 2018). Though non-degraded wetlands are mostly a C sink, they also account for a large natural source of GHG such as CH_4 and CO_2. Wetlands sequester C through high rates of organic matter inputs and reduced rates of decompositions (Pant, Rechcigl, and Adjei 2003). Wetland soils may contain as much as 200 times more C than its vegetation, alleviating the global climate change regardless of the emission of CH_4. As per Mitra (2003), estimates of the carbon sequestration potential of wetlands vary between 80 and 230 $TgCy^{-1}$. On the contrary, natural wetland emissions, with a median emission of 164 Tgy^{-1}, currently contribute up to approximately 40% of the global CH_4 emissions (Bridgham Cadillo-Quiroz, Keller, *et al.* 2013; Saunois eBousquet, Poulter, *et al.* 2016), and are thought to cause much of the yearly atmospheric CH_4 concentration variability (McNorton Chipperfield, Gloor, *et al.* 2016). One CH_4 molecule possesses 25 times higher global warming potential (GWP) per molecule than CO_2 over a period of 100 years. Current rates of its release are equivalent to nearly 6% of the global human CO_2 emissions (Joosten, Sirin, Couwenberg, *et al.* 2016). This may increase in warming climate and leading to a positive feedback on climate change. But through restoration, the wetlands can reverse them to a sink of atmospheric CO_2 (Lal 2008). Hence, due to the paucity of data about the amount of C stored and emitted from wetlands, depending on site-specific factors, the role of wetlands in the net global GHG emissions is conflicting and unclear.

Emissions

The CH_4 and CO_2 emissions from wetlands are influenced by seasonal, spatial, and geographic differences that result in high variations between different wetland types within the country. A number of studies worldwide and within India have examined CH_4 and CO_2 fluxes using various methods. However, uncertainties exist in estimating carbon emissions and sequestration in these vulnerable wetland habitats, and hinder the assessment of their importance.

Combining direct data and indirect estimation, we compiled studies involving 140 sites across India and globe, and estimated the average CO_2 emissions and sequestration per tonne (t) per hectare (ha^{-1}) per year (y^{-1}). This data was available only for 11 wetland types out of 19 provided by SAC 2011 and was used to extrapolate the emissions and sequestration of these specific 11 wetland types represented by our measurements to the whole of India and, thereby, estimate the influence of wetland net CO_2 storage on India's GHG inventory. Extrapolation of fluxes was done only for the open water area of inland waters. To account for seasonal variation in the emissions (Singh, Kulshreshtha, and Agnihotri 2000; Agarwal and Garg 2009) induced by change in the wetland water area, we considered average of post-monsoon and pre-monsoon open water areas in the extrapolation. Therefore, only about 6.6 Mha was considered for the estimate, though the total wetland water area for the 11 wetland types considered is 11.16 Mha (SAC 2011). Our estimate also excludes another 3.54 Mha under remaining 8 wetland types including natural and manmade waterlogged areas, inland saltpan areas and natural coastal wetlands such as lagoon, creek, sand/beach, intertidal mud flat, and coral reef. Wetlands <2.25 ha have also been excluded as most of them usually get dry in summer.

As per the available values of 2011, the total carbon dioxide emissions and sequestration from 11 types of inland and coastal wetlands covering 6.6 Mha, which is the average area of open water pre- and post-monsoon, are 30.72 million tonne of CO_2 y^{-1} and 24.79 million tonne of CO_2 y^{-1}, respectively. The total carbon dioxide emissions and sequestration pertaining to inland wetlands are 22.56 million tonne of CO_2 y^{-1} and 22.96 million tonne of CO_2 y^{-1}, respectively. Thus, the net GHG productions and annihilations are nearly balanced in their case.

However, in the case of coastal wetlands, the total carbon dioxide emissions and sequestration are 8.16 million tonne of CO_2 $y^{-1}$and 1.84 million tonne of $CO_2$$y^{-1}$, respectively. This could be because of the high salinity that leads to anoxic conditions prevailing. These conditions act as potential sources of CH_4 and N_2O since at a high rate of nutrient turnover, small leaks in nutrient cycles may result in high rates of emissions of these GHGs (Krithika Purvaja, and Ramesh 2008). Since mangrove regeneration under good conditions is likely to provide very high rates of sequestration where soil carbon is included, it is imperative to protect and conserve them.

Considering the average annual rate of natural wetland loss of -0.78% a year as estimated by the Wetland Estimate Trend (WET) Index (Ramsar 2018), the total carbon dioxide emissions and sequestrations account to 28.63 million tonne of CO_2 y^{-1} and 23.10 million tonne of CO_2 y^{-1} in 2020; 26.29 million tonne of CO_2 y^{-1} and 21.22 million tonne of CO_2 y^{-1} in 2030; and 21.65 million tonne of CO_2 y^{-1} and 17.47 million tonne of CO_2 y^{-1} in 2050, respectively.

Thus, the wetlands in India are acting as source than sink for GHGs. This may be due to drainage of large areas of wetlands and their subsequent cultivation at many places making them a net source of CO_2 as soil organic matter previously stored under anaerobic conditions is aerated and exposed to atmospheric oxygen. In many cases, the organic carbon stores that had accumulated slowly over centuries to millennia can be lost in days (in the case of burning) or over decades (IPCC 2001).

A few limitations have been observed in the study. The data used for estimating carbon emissions as well as sequestration potential is very old but as the only available data on inventory of wetlands recognized by the MoEFCC. However, as per Wetlands International South Asia (WISA) report 2020, India has lost nearly one-third of its natural wetlands to urbanization, agricultural expansion, and pollution over the last four decades. It has also translated in loss of many tonnes of carbon sequestrations potential

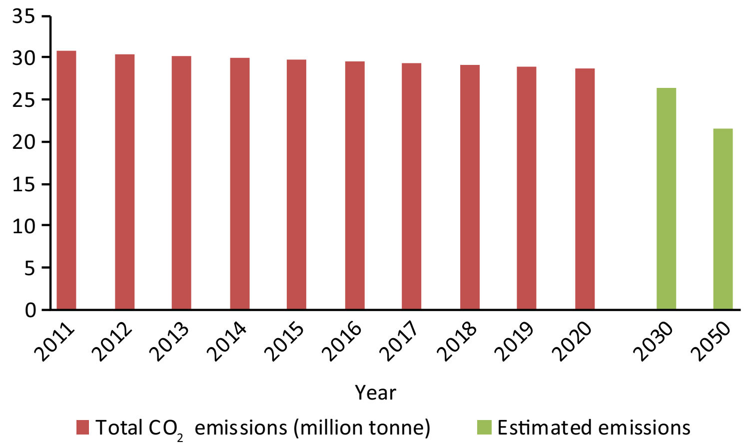


Figure 11 Total CO_2 emission and estimated emissions till 2050 from wetlands

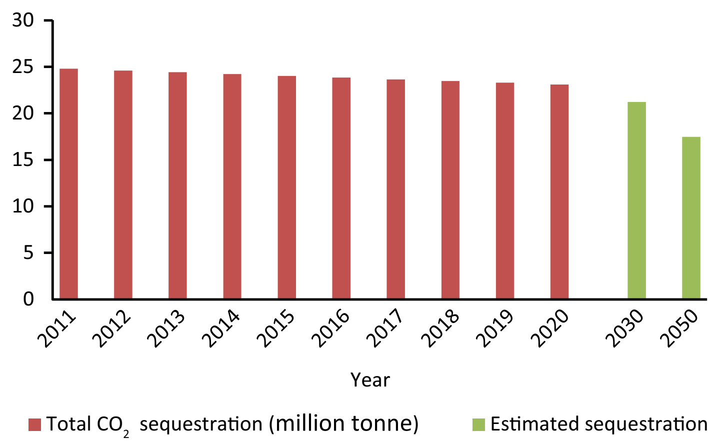


Figure 12 Total CO_2 sequestration and estimated sequestartion from wetlands

each year due to current rates of wetland destruction. Disturbed wetland soils like in the case of mangrove soils release an additional 11 million tonne of carbon annually (Patil, Singh, Naik, *et al.* 2012). Hence, focused research is needed to estimate the extent of wetlands of our country along with various trends that may result in more accurate estimates of the carbon emissions as well as sequestration potential.

Future potential to achieve land degradation neutrality

Research has shown that, compared to degraded sites, restored wetlands have lower carbon emission rates and over time, can become net carbon sinks (Joosten Sirin, Couwenberg, *et al.* 2016). Hydrological changes, particularly alterations in water table level in freshwater wetlands, influence carbon emissions by altering oxidation and reduction processes. Hence, rehabilitating a wetland's water table has the potential to restore the natural process of wetland soil carbon sequestration and storage (Limpert, Carnell, Trevathan-Tackett, *et al.* 2020). Similarly, in the case of coastal wetlands, restoring them, rewetting drained soils, preventing erosion, and reconnecting wetlands to exchange with saltwater can reduce more GHG emissions.

Agriculture

Indian agriculture is the second highest contributor of GHG in the world. India's NDCs have recognized agriculture as one of the priority sectors for GHG emission reduction. Agriculture predominantly contributes to the emission of high global warming potential (GWP) gases rich in CH_4 and N_2O mainly coming from enteric fermentation, synthetic fertilizer usage, and rice cultivation.

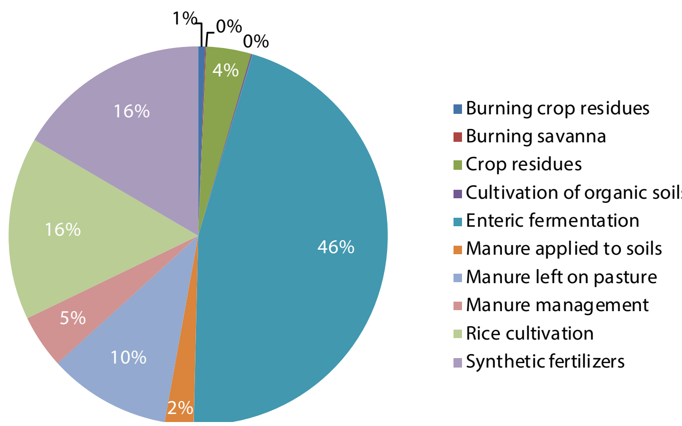
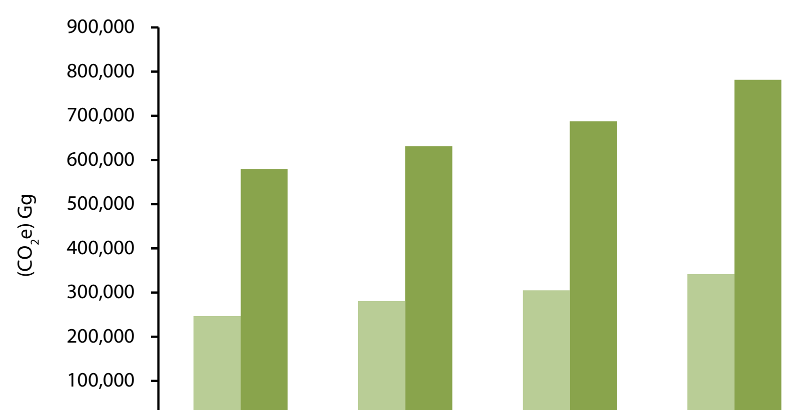


Figure 13 Major contributing source of GHG for agriculture

Emissions

The current estimates of emission from India's agriculture since 2005 (considering NDC targets; compared to 2005 emissions) is contributed by seven different agricultural emissions sub-domains (burning crop residues, cultivation of organic soils, cropland, manure application to soils, manure management, rice cultivation and synthetic fertilizers). Emission projections were calculated for both 2030 and 2050 based on a baseline defined as the 2005–2007 average of the equivalent FAOSTAT activity data (Alexandratos and Bruinsma 2012). Data for the 'Cultivation of organic soils' were obtained as per the FAOSTAT. The CO_2e of GHG is currently calculated using GWP-CH_4 = 21 and GWP-N_2O = 310 considering the time limitations and other technical constrains for this interim report. If needed, the GWP of these two gases will be revised as per the IPCC AR5 in the final report which will be submitted towards the end of this year. Additionally, emissions from land use for 'Cropland' were also presented. GHG emissions from this sub-domain of 'land-use' are presently restricted to CO_2 emissions from cropland organic soils. These values are estimated based on the carbon losses from drained histosols under cropland and expressed as net emissions/removal Gg CO_2e.

Taken together the average emissions (2005–2017) from these seven subsectors is 271,036 Gg and is projected to be 305,164 Gg by 2030 and 341,829 Gg by 2050 (Figure 14).



	2005	2015	2030	2050
Calculated sub-sectors	245,935.8	280,896.2	305,164.8	341,829.7
Agriculture total	579,795.6201	630,960.9553	686,973.0235	781,208.7782

Figure 14 Comparison with total agricultural emissions

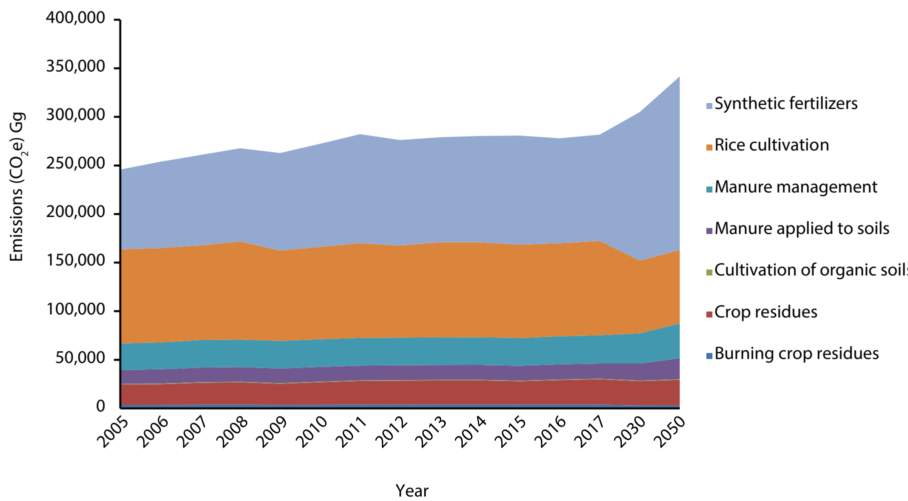


Figure 15 Emission highlights (CO_2e) Gg from the seven calculated sub-sectors

Sequestration

Soil organic carbon (SOC) is one of the most critical features of soils that result from the interaction of net primary producers, decomposers, and mineralogy. Potential for soil management for carbon sequestration in the form of SOC has been extensively studied over the past decades. The global average of SOC content per hectare is estimated to be 161 tonne (Minasny Malone, McBratney, *et al.* 2017). Supposing that the SOC sequestration rates of the 4PT initiative (4 per 1000) can be accomplished, the average global rate would require being 0.6 t C $ha^{-1}y^{-1}$ and this rate of SOC sequestration exceeding the rate for agricultural land. The current 4PT initiative, endorsed by the United Nations General Assembly at the 21st Conference of Parties 2015 (COP21), is an integrated approach to support SOC sequestration as a remedy to counterbalance fossil fuel CO_2 emissions; India's NDC also recognized agriculture as one of the priority sectors for GHG emission reduction. A meta-analysis of SOC reserve changes under conservation agriculture (CA) practices Indo-Gangetic Plains (IGP) was quantified. In IGP, the annual rise in SOC stock compared to conventional practice were between 0.16 and 0.49 Mg C $ha^{-1}y^{-1}$ caused by crop diversification will almost certainly constitute genuine mitigation potential which should not be overlooked (Powlson Stirling, Thierfelder, *et al.* 2016). The implementation of the System of Rice Intensification (SRI) in several areas has led to an emission decline of 0.18 $MTCO_2$ during 2010–16, while Direct Seeded Rice system has led to an emission reduction of 0.17 $MTCO_2$ from 2014–16. It clearly demonstrates the potential of economic agro-technologies for carbon sequestration.

Future potential to achieve land degradation neutrality

Degraded (but not polluted) agricultural soils have a greater prospective for sequester SOC. The measurable impacts will include increased soil fertility, land productivity for food production, and food security. This economic tool will also make agricultural processes more sustainable and help prevent or mitigate land resource degradation. Improving climate-resilient genotypes for Rice Wheat (RW) cropping systems and crop diversification with several other cropping systems are available, which can mitigate the problems arising from RW cropping system. Effective land use and management enable enhancing both soil organic carbon and above-ground carbon sequestration. Restoration of eroded lands with appropriate conservation measures can reverse soil degradation, improve productivity, and transform regenerated land as the potential of sequestration tool. Further, GHG emission hotspots identification and cost-effective mitigation opportunities in agriculture can help in making informed decisions towards the prioritizing of efforts to moderate emissions without conceding on food and nutrition security.

Moreover, there are proven and upcoming agro-technologies that can aid in accomplishing these ambitious goals of achieving land degradation neutrality. Carbon-neutral or negative management practices can have a synergistic impact on crop productivity, soil health, and GHG sequestration. These include the integrated application of economic, simple, and scalable technologies such as laser land levelling (helps in saving of irrigation water by up to 20% and improves the use), the efficiency of applied N, conservation tillage (zero/minimal tillage), bed planting (narrow/broad beds), direct-seeded rice, Sesbania brown manuring and other bio-fertilizer (including Arbuscular Mycorrhizal Fungi in Carbon Sequestration), use of leaf colour chart (LCC), residue retention for mulch, integrated nutrient and pest management, agroforestry (Direct role: Carbon sequestration rates ranging from 1.5 to 3.5 Mg C $ha^{-1}y^{-1}$ in agroforestry systems) and application of Biochar, etc. It was estimated by an independent study that by 2030, under business-as-usual, GHG emissions from the agricultural sector in India would be 515 megatonne CO_2 equivalent ($MTCO_2e$) per year with a technical mitigation potential of 85.5 $MTCO_2e$ per year through the implementation of several mitigation practices (Sapkota Vetter, Jat, *et al.* 2019). This study further highlighted that about 80% of the technical mitigation potential could be attained by implementing only cost-saving measures. Three mitigation choices, i.e. effective use of fertilizer, zero-tillage, and rice-water management, could bring more than 50% of the total technical reduction potential. Climate compatible crop development for the future using new horizon game changing technologies such as CRISPR/Cas9 and nano-fertilizers for precision agriculture (integrated nutrient management) has not been talked much for GHG emissions. By employing GHG compliance genetic selection, breeding, and genome editing for designer traits (improved nutilization efficiency, photosynthetic capacity, climate resilience, and cattle gut digestibility, etc.) could be critical in bringing newer genotypes for these specific purposes. Effective carbon sequestration in major cropping systems in India needs know-how, proper technology dissemination channel, financial reward system, and government policies. Any single practice cannot improve the SOC in the soil. There is a need for a multidisciplinary approach with multiple R&D institutions, farmers, and policymakers to collectively address this complex challenge and meet the national sustainable development goals.

Discussion

A stakeholder consultation was conducted in the presence of the Secretary, MoEFCC, Government of India. Speakers from Department of Agriculture and Department of Land Resources were also present during the consultation. A few suggestive actions were recommended during the discussion and accepted by concerned ministries of the Government of India:

- The data available in the context of land degradation in India is fragmented. The Centre of Excellence for sustainable land management to be set up in ICFRE must harmonize the data and overlapping schemes and also integrate with institutions dealing with land management issues.
- The status of emissions from land-use sector must be reviewed every five years to take corrective measures in the policies and programmes for achieving land degradation neutrality.
- Forest Survey of India should provide the data of fuelwood consumption (from both recorded forests and TOF) biannually in the India State of Forest Report so that the state-wise consumption of fuelwood and the exact estimates of emission and sequestration potential can be known, and policymakers may initiate strategies accordingly.
- Forest Survey of India should provide the data related to forest cover within the recorded forest area and also for TOF separately.
- The Government of India should adopt the policy of carbon neutrality under the Polluter Pays Principle and Payment Mechanism for Ecosystem Services as mandated in the fundamental right under Article 21 of the Indian constitution.
- Implementation of agroforestry policy in true spirit and also creating better market for agroforestry produce such as higher import duty, quality planting material, rationalize, transit (which will be valid for pan-India) and felling rules, and rules for wood-based industries. The MoEFCC has decided to introduce pan-India transit permit for timber, bamboo, and other forest produce.

- Technologies that can reduce the amount of methane production in rumen or total release of methane into atmosphere should be adopted for efficient use of feed. Mitigation of GHG emissions from animal husbandry sector can be achieved by decreasing the emission rate due to enteric fermentation. Different animal feeding management, manure management (collection, storage, spreading), management of feed crop production, and dietary manipulation are the key strategies.
- The extent of wetlands both within and outside the forests along with various trends that may result in more accurate estimates of the carbon emissions as well as sequestration potential should be provided in the India State of Forest Report by the Forest Survey of India.
- The Ministry of Mines (MoM) should develop a centralized database of all the post-mining restoration initiatives undertaken by the agencies. Key aspects such as tree species, age, height, girth, etc. should be regularly documented along with the carbon sequestered by the trees every 5 years. The plantations should adopt scientific processes in which ecological succession should be followed to ensure restoration of habitat suitable for the local biodiversity.
- Monitoring mechanism should be adopted and followed regularly as per the guidelines issued by the MoM. Rehabilitation of mines should be undertaken regularly to reduce and mitigate the emissions from the mining sector.
- Climate compatible crop development for the future using new horizon game changing technologies such as mycorrhizal technology, integrated nutrient management, CRISPR/Cas9, and nano-fertilizers for precision agriculture must be promoted.
- Carbon-neutral practices should be adopted in the agriculture sector in order to have a synergistic impact on crop productivity, soil health, and on GHG sequestration.

Conclusion

This study provides estimates of CO_2 emissions, status of sequestration, and sequestration/emission reduction potential in order to achieve land degradation neutrality from different land-use sectors in India. The total emission from the seven land-use sectors in 2020 is estimated to be 1113.03 million tonne of CO_2e, which is projected to increase to 1240.23 million tonne of CO_2e and 1340.87 million tonne of CO_2e till 2030 and 2050, respectively.

From Table 3 it can be inferred that the forestry sector (48.43%) is the major contributor of emissions out of the five sectors, followed by agriculture (24.35%) and animal husbandry (22.33%). In order to achieve the forestry

Table 3. Emissions from different land use sectors in India

Land-use Sector	Emissions in 2020 (million tonne of CO_2e)	Emissions in 2030 (million tonne of CO_2e)	Emissions in 2050 (million tonne of CO_2e)
Forestry	539.13	626.91	680.12
Fuelwood	503.45	579.01	620.46
Forest fire	8.18	9.40	10.06
Paper and pulp	27.5	38.5	49.6
Animal husbandry	248.58	254.53	266.60
Mining	25.66	27.33	30.67
Wetlands	28.63	26.30	21.65
Agriculture	271.03	305.16	341.83
Total	**1113.03**	**1240.23**	**1340.87**

NDC target, the level of emissions in the forestry sector needs to be reduced. This can be done by promoting the use of LPG instead of fuelwood in the forest and forest -fringe villages as LPG has 90% efficiency and this will further reduce the emissions by 453.10 million tonne of CO_2e. Also, due to the digital transformation during this pandemic, paper and plastic use has been reduced to a great extent which will help in emission reduction but enhance the emissions of forestry sector by using more paper by the packaging industry. This discussion along with many other we had in the past in the context of agroforestry has influenced the MoEFCC to make policy decision to have pan-India transit pass mechanism for forest produce which would help in achieving forestry NDC and motivate farmers to grow more trees, and also help in achieving land degradation neutrality.

References

Adhikari, S., Lal, R. and Sahu, B.C. 2012.Carbon sequestration in the bottom sediments of aquaculture ponds of Orissa, India. *Ecological Engineering*, **47**: 198-202.

Agarwal, R., and Garg, J.K. 2009. Methane emission modelling from wetlands and waterlogged areas using MODIS data. *Current Science,* **96**: 36-40.

Aleksandrowicz, L., Green, R., Joy, E.J., Harris, F., Hillier, J., Vetter, S.H., Smith, P., Kulkarni, B., Dangour, A.D. and Haines, A. 2019. Environmental impacts of dietary shifts in India: A modelling study using nationally-representative data. *Environment International*, **126**: 207-215.

Bernal, B. and Mitsch, W.J. 2013. Carbon sequestration in two created riverine wetlands in the Midwestern United States. *Journal of Environmental Quality*, **42**(4): 1236-1244.

Boyd, C.E., Wood, C.W., Chaney, P.L. and Queiroz, J.F. 2010. Role of aquaculture pond sediments in sequestration of annual global carbon emissions. *Environmental Pollution*, **158** (8): 2537-2540.

Bridgham, S. D., Cadillo-Quiroz, H., Keller, J. K., and Zhuang, Q. 2013. Methane emissions from wetlands: biogeochemical, microbial, and modeling perspectives from local to global scales. *Glob*. *Change Biol*., **19**: 1325–1346.

Broadhead, J.S. 2011. Reality check on the potential to generate income from mangroves through carbon credit sales and payments for environmental services. Regional Fisheries Livelihoods Programme for South and Southeast Asia (GCP/RAS/237/SPA) Field Project Document 2011/REG/2.

Chmura, G. L., Anisfeld, S. C., Cahoon, D. R., and Lynch, J. C. 2003. Global carbon sequestration in tidal, saline wetland soils,. *Global Biogeochem. Cycles*, **17**(4): 1111.

Das, R. and Maiti, S. 2016. Estimation of carbon sequestration in reclaimed coalmine degraded land dominated by *Albizia Lebbeck, Dalbergia Sissoo and Bambusa Arundinacea* plantation: a case study from Jharia Coalfields, India. *Int J Coal SciTechnol*, 3(2): 246–266.

FAO. 2006. *Livestock's Long Shadow*. Rome: Food and Agriculture Organization.

FAOSTAT. 2019. *Statistical Data*. Rome: Food and Agriculture Organization.

Fawei, Z., Anhua, L., Yingnian, L., Liang, Z., Qinxue, W. and Mingyuan, D. 2008. CO_2 flux in alpine wetland ecosystem on the Qinghai-Tibetan Plateau, China. *ActaEcologicaSinica*, **28**(2): 453-462.

Flannigan, M., Stocks, B.J., Turretsky, M., and Wotton, M. 2008. Impacts of climate change on fire activity and fire management in the circumboreal forest,. *Global Change Biology*, **15**(3): 549-560.

Ghosh, K., Bardhan, S. and Roy, S. 2017. An assessment of the annual carbon sequestration potential of urban and peri-urban water bodies and wetlands. *IARJSET*. **4**:86-93.

Gorham, E. 1995.The biogeochemistry of northern peatlands and its possible responses to global warming. *Biotic feedbacks in the global climate system: Will the warming feed the warming*, pp.169-187.

Government of India. 2015. Statistics related to climate change – India, New Delhi: Ministry of Statistics and Programme Implementation, Central Statistics Office.

Government of India (GoI). 2004. India's initial National Communication (NATCOM) to UN-FCCC, Ministry of Environment and Forests, New DelhiGreen, R.F., Joy, E.J., Harris, F., Agrawal, S., Aleksandrowicz, L., Hillier, J., Macdiarmid, J.I., Milner, J., Vetter, S.H., Smith, P. and Haines, A. 2018. Greenhouse gas emissions and water footprints of typical dietary patterns in India. *Science of the Total Environment*, **643**: 1411-1418.

Indian School of Mines. 2015. Carbon Sequestration Study at Eco-restoration Sites of BCCL, Department of Environmental Science and Engineering, Centre of Mining Environment, Dhanbad.

IPCC. 2001: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds)]. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

IUCN. 2016. *Making the Case for Forest Restoration: A guide to engaging companies*. Gland, Switzerland: IUCN.

Joosten, H., Sirin, A., Couwenberg, J., Laine, J. and Smith, P. 2016. The role of peatlands in climate regulation. *Peatland restoration and ecosystem services: Science, policy and practice*, p.66.

Kangabam, R.D., Kanagaraj, S., and Munisamy, G. 2016. Assessment of carbon sequestration potential of Loktak Lake in Manipur-a biodiversity hotspot. *International Journal of Conservation Science*, **7**(4) :1145-1152.

Kekkonen, H., Ojanen, H., Haakana, M., Latukka, A., and Regina, K. 2019. Mapping of cultivated organic soils for targeting greenhouse gas mitigation. *Carbon Management*, **10**(2): 115-126.

Kim, D.G., Thomas, A., Pelster, D., Rosenstock, T.S., and Sanz-Cobena, A. 2016. Greenhouse gas emissions from natural ecosystems and agricultural lands in sub-Saharan Africa: synthesis of available data and suggestions for further research. *Biogeosciences*, **13**(16): 4789-4809.

Krithika, K., Purvaja, R. and Ramesh, R. 2008. Fluxes of methane and nitrous oxide from an Indian mangrove. *Current Science*, pp. 218-224.

Lal, R. 2008.Sequestration of atmospheric CO_2 into global carbon pool. *Energy EnvSci*, **1**:86-100.

Limpert, K.E., Carnell, P.E., Trevathan-Tackett, S.M. and Macreadie, P.I. 2020. Reducing emissions from degraded floodplain wetlands. *Frontiers in Environmental Science*. DoI: https://doi.org/10.3389/fenvs.2020.00008

Lok Sabha. 2017. Unstarred Question No. 3470, dated on 08.08.2017.

Lok Sabha 2018. Unstarred Question No. 2842, dated on 03.08.2018.

Ma, Y., Sun, L., Liu, C., Yang, X., Zhou, W., Yang, B., Schwenke, G., and Li Liu, D. 2018. A comparison of methane and nitrous oxide emissions from inland mixed-fish and crab aquaculture ponds. *Science of the Total Environment*, **637**: 517-523.

McNorton, J., Chipperfield, M. P., Gloor, M., Wilson, C., Feng, W., Hayman, G. D., Rigby, M., Krummel, P. B., O'Doherty, S., Prinn, R. G., Weiss, R. F., Young, D., Dlugokencky, E., and Montzka, S. A. 2016. Role of OH variability in the stalling of the global atmospheric CH_4 growth rate from 1999 to 2006. *Atmos. Chem. Phys.*, **16**: 7943–7956.

Minasny, B., Malone, B.P., McBratney, A.B., Angers, D.A., Arrouays, D., Chambers, A., Chaplot, V., Chen, Z.S., Cheng, K., Das, B.S., and Field, D.J. 2017. Soil carbon 4 per mille. *Geoderma*, **292**: 59–86.

Mitra, S., Wassmann, R., and Vlek, P.L. 2003. Global inventory of wetlands and their role in the carbon cycle (No. 64). ZEF *Discussion Papers on Development Policy*.

Mitsch, W.J. and Gosselink, J.G. 2015. *Wetlands*, 5th ed. Hoboken, NJ: John Wiley & Sons.

Mohan, R. R., Dharmala, N., Anantha Kumar, M. R., Kumar, P., and Bose, A . 2019. *Greenhouse Gas Emission Estimates from the Energy Sector in India at the Subnational Level (Version/edition 2.0)*. New Delhi. GHG Platform India Report - CSTEP.

Mukhopadhyay, S., Masto R., and Ram L. 2015. Soil quality and carbon sequestration in a reclaimed coal mine spoil of Jharia coalfield, India.; G*eophysical Research Abstracts*, **18**, EGU2016-450-1, 2016.

Murthy, T.V.R., Patel, J.G., Panigrahy, S., and Parihar, J.S. 2011. National Wetland Atlas: Wetlands of international importance under Ramsar convention. Ahmedabad: Space Applications Centre (ISRO).

Ouyang, X. and Lee, S.Y. 2013. Carbon accumulation rates in salt marsh sediments suggest high carbon storage capacity. *Biogeosciences Discussions*, **10**(12): 19-155.

Pandey, K., Priyaranjan Sahu, J., and Thakur, P. 2018a. Ujjwala scheme: Are cleaner cooking fuels affordable and accessible?, *Down to Earth*, February.

Pandey B., Gautam M., and Agarwal M. 2018b. Greenhouse gas emissions from coal mining activities and their possible mitigation strategies, environmental carbon footprints. In *Environmental Carbon Footprints*, Subramanian Senthilkannan Muthu (ed.). Cambridge, MA: Elsevier.

PanneerSelvam, B., Natchimuthu, S., Arunachalam, L. and Bastviken, D. 2014. Methane and carbon dioxide emissions from inland waters in India–implications for large scale greenhouse gas balances. *Global Change Biology*, **20**(11): 3397-3407.

Pant, H.K., Rechcigl, J.E., and Adjei, M.B. 2003. Carbon sequestration in wetlands: concept and estimation. *Food, Agriculture & Environment*, **1**(2): 308-313.

Parikh, J., Panda, M., Ganesh-Kumar, A., and Singh, V. 2009. CO_2 emissions structure of Indian economy. *Energy*. 34: 1024-1031.

Parikh, J. and Gokarn, S. 1993. Climate change and India's energy policy options. *Global Environmental Change*, **3**(3): 276

Patil, V., Singh, A., Naik, N., Seema, U., and Sawant, B. 2012.Carbon sequestration in mangroves ecosystems. *Journal of Environmental Research and Development*, **7**(1A): 576-583.

Pendleton, L., Donato, D.C., Murray, B.C., Crooks, S., Jenkins, W.A., Sifleet, S., Craft, C., Fourqurean, J.W., Kauffman, J.B., Marbà, N. and Megonigal, P. 2012. Estimating global "blue carbon" emissions from conversion and degradation of vegetated coastal ecosystems. *PloS one*, **7**(9).

Powlson, D.S., Stirling, C.M., Thierfelder, C., White, R.P., and Jat, M.L. 2016. Does conservation agriculture deliver climate change mitigation through soil carbon sequestration in tropical agro-ecosystems? *Agriculture, Ecosystems & Environment*, **220**: 164-174.

Sapkota, T.B., Vetter, S.H., Jat, M.L., Sirohi, S., Shirsath, P.B., Singh, R., Jat, H.S., Smith, P., Hillier, J. and Stirling, C.M. 2019. Cost-effective opportunities for climate change mitigation in Indian agriculture. *Science of the Total Environment*, **655**: 1342-1354.

Sasan power Limited. 2010. Greenhouse gas emissions from coal mine.

Saunois, M., Bousquet, P., Poulter, B., Peregon, A., Ciais, P., Canadell, J.G., Dlugokencky, E.J., Etiope, G., Bastviken, D., Houweling, S., and Janssens-Maenhout, G. 2016. The global methane budget 2000–2012. *Earth System Science Data*, **8**(2): 697-751.

Shaher, S., Chanda, A., Hazra, S., and Mukherjee, A.D. 2019. Status of Methane Emission from Indian Wetlands (Saline vs. Freshwater): A Mini Review. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, pp.1-7.

Sharma S.K., Bhattacharya S., and Garg A. 2006. Greenhouse gas emissions from India: a perspective. *Current Science*, **90**(3) : 326-333..

Shyamsundar, P., Springer, N.P., Tallis, H., Polasky, S., Jat, M.L., Sidhu, H.S., Krishnapriya, P.P., Skiba, N., Ginn, W., Ahuja, V., and Cummins, J., 2019. Fields on fire: Alternatives to crop residue burning in India. *Science*, **365**(6453): 536-538.

Singh, A. and Jaywardhan, K. 2016. Fugitive methane emissions from Indian coal mining and handling activities: estimates, mitigation and opportunities for its utilization to generate clean energy., *Energy Procedia*, **90**: 336–348.

Singh S.N., Kulshreshtha K., and Agnihotri, S. 2000. Seasonal dynamics of methane emission from wetlands. *Chemosphere - Global Change Science*, **2**: 39-46.

Taylor, S., Gilbert, P.J., Cooke, D.A., Deary, M.E., and Jeffries, M.J. 2019. High carbon burial rates by small ponds in the landscape. *Frontiers in Ecology and the Environment*, **17**(1): 25-31.

Thomas, A.D., Dougill, A.J., Elliott, D.R., and Mairs, H. 2014. Seasonal differences in soil CO_2 efflux and carbon storage in Ntwetwe Pan, Makgadikgadi Basin, Botswana. *Geoderma*, **219**: 72-81.

Tibrewal, K. 2016. Application of Carbon Footprint in Mining Industry, Thesis, Department of Mining Engineering, National Institute of Technology, Rourkela.

Tripathi, N., Singh R., and Hills, C. 2016. Soil carbon development in rejuvenated Indian coal mine spoils., *Ecological Engineering*, **90**: 482-490.

Venkataraman, C., Habib, G., Kadamba, D., Shrivastava, M., Leon, J.-F., Crouzille, B., Boucher, O., and Street, D. G. 2006. Emissions from open biomass burning in India: Integrating the inventory approach with high-resolution Moderate Resolution Imaging Spectroradiometer (MODIS) active-fire and land cover data., *Global Biogeochem. Cycles,* **20**.

Vetter, S.H., Sapkota, T.B., Hillier, J., Stirling, C.M., Macdiarmid, J.I., Aleksandrowicz, L., Green, R., Joy, E.J., Dangour, A.D., and Smith, P. 2017. Greenhouse gas emissions from agricultural food production to supply Indian diets: Implications for climate change mitigation. *Agriculture, Ecosystems & Environment*, **237**: 234-241.

THE ENERGY AND RESOURCES INSTITUTE
Creating Innovative Solutions for a Sustainable Future